AP Physics 1 Facts – for 2025 exam

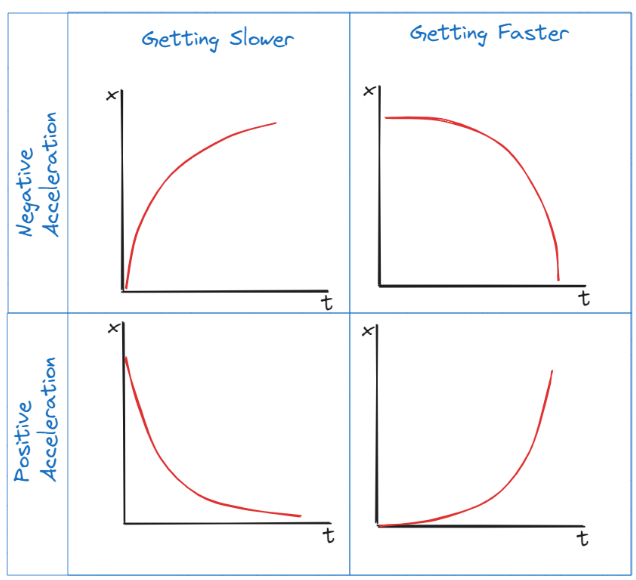
1 Kinematics

1.1 Kinematic Definitions

- Displacement, Δx or Δy, indicates how far an object ends up from its initial position, regardless of its total distance traveled.
- Average velocity, $\bar{v}$, is displacement divided by the time interval over which that displacement occurred.
- Instantaneous velocity, v, is how fast an object is moving at a specific moment in time.
- Average Speed is total distance divided by time duration.

1.2 Position-time graphs

- To determine *how far* from the detector an object is located, look at the vertical axis of the position-time graph.
- To determine *how fast* an object is moving, look at the steepness (i.e. the slope) of the position-time graph.
- To determine *instantaneous speed* from a curved position-time graph, take the slope of a tangent line.
- To determine which *way the object is moving*, look at which way the position-time graph is sloped.
  - A position-time slope like a front slash / means the object is moving away from the detector.
  - A position-time slope like a back slash \ means the object is moving toward the detector.
- *Concave up*, a U shape, indicates a positive acceleration
- *Concave down*, a frown, indicates a negative acceleration
- There are four basic shapes, that can be combined, that show uniform acceleration. You should know each.



1.3 Velocity-time graphs

- To determine *how fast (speed)* an object is moving, look at the vertical axis of the velocity-time graph.
- To determine *which way the object is moving*, look at whether the velocity-time graph is above or below the horizontal axis.

  - An object is moving away from the detector if the velocity-time graph is above the horizontal axis.
  - An object is moving toward the detector if the velocity-time graph is below the horizontal axis.

- To determine *how far an object travels* (displacement), determine the *area between the velocity-time graph and the horizontal axis*.
- On a velocity-time graph it is not possible to determine the location of the object.
- The *slope* of a velocity-time graph is **acceleration**.

1.4 Acceleration

- Acceleration tells how much an object's speed changes in one second.
- When an object speeds up, its acceleration is in the direction of motion.
- When an object slows down, its acceleration is opposite the direction of motion.
- The acceleration of an object in free fall is g and near the surface of the earth this is 10 m/s^2 near the surga.
- The units of acceleration are m/s^2 or m/s/s.

1.5 Special equations for displacement

- When an object is moving at a constant speed v, its displacement is given by $\Delta x = vt$.
  - This includes *horizontal* components of projectile motion
- When an object starts at rest and speeds up, or when an object slows to a stop, its displacement is given by either $x = \frac{1}{2}at^2$ or $x = v_0 t + \frac{1}{2}at^2$

1.6 Algebraic kinematics

You must follow these steps to solve an algebraic kinematics calculation.

1. Define a positive direction, i.e. the direction "away from the detector. Label that direction.
2. Indicate in words what portion of motion you are considering, e.g. "motion from launch to the peak of the flight."
3. Fill out a cross diagram chart, including signs and units, of the five kinematics variables:

	Δx [displacement]	
v_0 [initial velocity]	a [acceleration]	v_f [final velocity]
	t [time for motion to happen]	

4. If three of the five variables are known, the problem is solvable; use the kinematics equations to solve.

$$v_f = v_o + at$$
$$x = v_o t + \frac{1}{2}at^2$$
$$v_f^2 = v_o^2 + 2ax$$

   A fourth equation may occasionally be useful (this is the area of a velocity vs. time graph written as the area of a trapezoid):

$$x = \frac{1}{2}t(v_o + v_f)$$

1.7 Projectile motion

- When an object is in free-fall,
  - its VERTICAL acceleration is always g or 10 m/s^2 near the surface of the earth.
  - *its HORIZONTAL acceleration is always zero*. Meaning the only equation you use for the horizontal motion is $\Delta x = vt$
- Velocities in perpendicular directions add with the Pythagorean theorem, just like perpendicular forces.
- The magnitude of an object's velocity is known as its speed.
- To approach a projectile problem, make two kinematics charts: one vertical, one horizontal.

1.8 Rotational kinematics – Definitions

- Angular displacement indicates the angle through which an object has rotated. It is measured in radians.
- Average angular velocity is angular displacement divided by the time interval over which that angular displacement occurred. It is measured in rad/s.
- Instantaneous angular velocity is how fast an object is rotating at a specific moment in time.
- Angular Acceleration tells how much an object's angular speed changes in one second. It is measured in rad/s per second.
- Angular acceleration and centripetal acceleration are independent. Angular acceleration changes an object's rotational speed, while centripetal acceleration changes an object's direction of motion.
- The constant-acceleration kinematics equations for rotation are essentially identical to those for linear motion:

$$\omega_f = \omega_0 + \alpha t$$
$$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$$
$$\omega_f^2 = \omega_0^2 + 2\alpha\theta$$

1.9 Relationship between angular and linear motion

- The linear displacement of a rotating object is given by $x = r\theta$, where r is the distance from the rotational axis.
- The linear speed of a rotating object is given by $v = r\omega$
- The linear acceleration of a rotating object is given by $a = r\alpha$.

2 Dynamics

2.1 Definition of Equilibrium

- An object is in equilibrium if it is moving in a straight line at constant speed. This includes an object remaining at rest.
- When an object is in equilibrium, forces on that object are balanced.

2.2 Newton's Second Law

- For all forces other than the force of the earth, objects must be in contact in order to experience a force.
- An object's acceleration is in the direction in which forces are unbalanced.
- The net force is in the direction in which the forces are unbalanced.
- The net force is in the direction of acceleration

$$\Sigma F = ma$$

2.3 Solving problems with forces

The two-step problem solving process:

1. Draw a free-body diagram.
   1a. Break angled forces into components, if necessary.
2. Write two equations, one for Newton's second law in each direction:

$$\text{(up forces)} - \text{(down forces)} = ma_y$$
$$\text{(left forces)} - \text{(right forces)} = ma_x$$

   Note that you should never get a "negative" force, so start the equations in the direction of acceleration. If acceleration is downward, write (down forces) $-$ (up forces) $= ma$ instead.

2.4 Mass and Weight

- Mass tells how much material is contained in an object.
- The units of mass are kilograms (kg).
- Weight is the force of a planet acting on an object (in newtons).
- On earth's surface, the gravitational field is 10 N/kg. This means that on earth, 1 kg of mass weighs 10 N.

2.5 Normal force

- A normal force is the force of a surface on an object in contact with that surface.
- A normal force acts perpendicular to a surface.
- A platform scale (i.e. bathroom scale) reads the normal force.

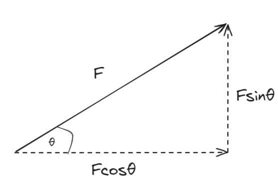
2.6 Adding perpendicular forces

- To determine the resultant force, use the Pythagorean theorem on the horizontal and vertical components.
- The "magnitude" of a force means the amount of the resultant force.

2.7 x- and y-components

When the angle of the diagonal force is measured from the horizontal,

- The horizontal component of the force is the magnitude of the force times $\cos\theta$ or $F_x = F\cos\theta$
- The vertical component of the force is the magnitude of the force times $\sin\theta$ or $F_y = F\sin\theta$



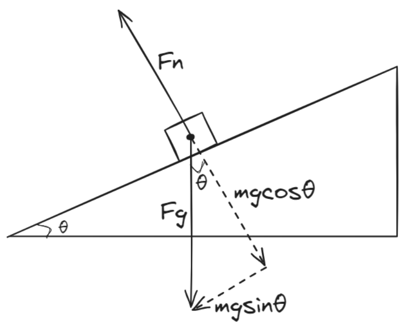
2.8 A free-body diagram includes:

1. A labeled arrow representing each force. Each arrow begins on the object and points in the direction in which the force acts.
2. A list of the forces, indicating the object applying the force and the object experiencing the force.

2.9 Inclined Planes

When an object is on a ramp, break the object's weight into components parallel to and perpendicular to the incline. Do not use x and y axes.

- The component of the object's weight parallel to the incline is $mg\sin\theta$
- The component of the object's weight perpendicular to the incline is $mg\cos\theta$



2.10 Friction force

- The force of friction is the force of a surface on an object acting along the surface.
- The force of friction acts in the opposite direction of an object's motion (relative to a surface).
- The coefficient of friction is not a force.
- The coefficient of friction is a number that tells how sticky two surfaces are
- The force of friction is equal to the coefficient of friction times the normal force

$$F_f = \mu F_n$$

- The coefficient of kinetic friction is used when an object is moving; the coefficient of static friction is used when an object is not moving. Both types of coefficients of friction obey the same equation.
- The coefficient of static friction can take on any value up to a maximum, which depends on the properties of the materials in contact.
- For two specific surfaces in contact, the maximum coefficient of static friction is greater than the coefficient of kinetic friction.

2.11 Newton's Third Law

- Newton's Third Law says that the force of object A on object B is equal to the force of object B on object A.
- A "Third Law Force Pair" is a pair of forces that obeys Newton's third law.
- Two forces in a third law force pair can never act on the same object.

2.12 Two-body problems

In a two-body problem, usually:

- Draw one free body diagram per object
- Write $F_{\text{net}} = ma$ for each object separately.
- acceleration is the same for each object
- One rope = one tension

3 Circular motion

- An object moving at constant speed v in a circle of radius r has an acceleration of magnitude v^2/r, directed toward the center of the circle.
- **Centripetal Force** is the net force that creates uniform circular motion.
  - The centripetal force is the sum of all of the *radial* forces (forces along the radius)

3.1 Gravitation

- All massive objects attract each other with a gravitational force.
- The gravitational force F_G of one object on another is given by

$$F_G = G\frac{m_1 m_2}{r^2}$$

  where
  - m is the mass of an object
  - r is the distance between the centers of the two objects
  - G is the universal gravitation constant, 6.7×10^{-11} Nm^2/kg^2
- The gravitational field g near an object of mass M is given by

$$g = G\frac{M}{d^2}$$

  where d represents the distance from the object's center to anywhere you're considering.
- The weight of an object near a planet is given by mg, where g is the gravitational field due to the planet at the object's location.
- The gravitational field near a planet is always equal to the free-fall acceleration.
- **Gravitational mass** is measured by measuring an object's weight using $W = mg$
- **Inertial mass** is measured by measuring the net force on an object, measuring the object's acceleration, and using $F_{\text{net}} = ma$.
- *In all experiments ever performed, gravitational mass is equal to inertial mass.*

3.2 Orbits

In a circular orbit of a satellite around a planet, consider the planet-satellite system:

- Kinetic energy is constant (same speed)
- Gravitational potential energy is constant (same orbital radius)
- Angular momentum mvr is constant (no external torques)
- Total mechanical energy is constant (no external work, and no internal energy)

To find the speed of a circular orbit, set gravitational force equal to ma, with $a = v^2/r$.
In an elliptical orbit of a satellite around a planet, consider the planet-satellite system:

- Kinetic energy is NOT constant (speed changes)
- Gravitational potential energy is NOT constant (orbital radius changes)
- Angular momentum mvr is constant (no external torques)
- Total mechanical energy is constant (no external work, and no internal energy)

Escape velocity is the minimum speed necessary for an object on the surface of a planet to reach a position far away from the planet. To find escape velocity, set total mechanical energy of an object-planet system to zero:

$$-\frac{GMm}{r} + \frac{1}{2}mv^2 = 0$$

4 What is conserved?

Mechanical energy is conserved when there is no net work done by external forces. (And when there's no internal energy conversion.)
Angular momentum is conserved when no net external torque acts.
Momentum in a direction is conserved when no net external force acts in that direction.

5 Energy

5.1 Equations for different forms of energy

All forms of energy have units of joules, abbreviated J.

- Kinetic energy: $K = \frac{1}{2}mv^2$. Here, m is the mass of the object, and v is its speed.
- Gravitational potential energy: $U_g = mgh$. Here, m is the mass of the object, g is the gravitational field strength, and h is the vertical height of the object above its lowest position.
- The term **mechanical energy** refers to the sum of a system's kinetic and potential energy.
- Spring potential energy: $U_s = \frac{1}{2}kx^2$. Here, k is the spring constant, and x is the distance the spring is stretched or compressed from its equilibrium position. (See the section below about springs)
- Rotational kinetic energy: $K_r = \frac{1}{2}I\omega^2$. Here, I is the rotational inertia of the object, and ω is the angular speed of the object.
- Internal energy is heat energy that causes an increase in the temperature of the system

5.2 Work-energy theorem

Problem-solving process:

- define the object or system being described.
- Define the two positions you're considering
- Draw an annotated energy bar chart
- Write an equation based on the energy bar chart, with one term per bar
  - $E_{\text{initial}} \pm Work = E_{\text{final}}$

5.3 Definition of Work

- *Positive* work is done by a force parallel to an object's displacement.
- *Negative* work is done by a force antiparallel to an object's displacement.
- No work is done by a force acting perpendicular to an object's displacement
- Work is a scalar quantity – it can be positive or negative, but does not have a direction.
- The area under a force vs. displacement graph is work.

5.4 Power

- Power is defined as the amount of work done in one second, or energy used in one second: $power = work/time$
- The units of power are joules per second, which are also written as watts.
- An alternate way of calculating power when a constant force acts is $power = force \cdot (average) velocity$ or $P = F\bar{v}$

5.5 Gravitational potential energy

- Near the surface of a planet, the potential energy of a planet-object system is mgh, with $h = 0$ at the lowest point of the motion.
- Away from the surface, the potential energy of a planet-object system is treated differently:
  - PE is larger the farther from the planet's center.
  - PE has a negative value (except when the object is way far away from the planet, in which case PE is zero).
  - The equation for potential energy is $PE = -\frac{GMm}{r}$. Don't use this equation unless you must derive an expression. The negative sign is confusing.

5.6 Energy in a collision

- In an elastic collision, mechanical energy of the system is conserved.
- Collisions for which objects stick together can not be elastic.
- Collisions for which object bounce off each other may or may not be elastic.

6 Momentum

- Momentum is equal to mass times velocity: $p = mv$
- The standard units of momentum are newton·seconds, abbreviated N·s. (Equivalent to kg·m/s)
- The direction of an object's momentum is always the same as its direction of motion.

6.1 Impulse

- Impulse, J, can be calculated in either of two ways:
  1. Impulse is equal to the change in an object's momentum
  2. Impulse is equal to the force experienced multiplied by the time interval of collision, $J = Ft$
- Impulse has the same units as momentum, N·s.
- Impulse is the area under a force vs. time graph.

6.2 Conservation of momentum in collisions

- When no external forces act on a system of objects, the system's momentum can not change.
- The total momentum of two objects before a collision is equal to the objects' total momentum after the collision.
- Momentum is a vector: that is, total momentum of two objects moving in the same direction adds together; total momentum of two objects moving in opposite directions subtracts.
- A system's center of mass obeys Newton's second law: that is, the velocity of the center of mass only changes when an external net force acts on the system.
- The location of the center of mass is given by $M_{tot}x_{cm} = m_1x_1 + m_2x_2 + \ldots$

7 Rotation

7.1 Torque

The **torque** provided by a force is given by $\tau = Fd_\perp$, where $d_\perp$ refers to the "lever arm"

7.2 Rotational Inertia

- Rotational inertia I represents an object's resistance to angular acceleration.
- For a point particle, rotational inertia is MR^2, where M is the particle's mass, and R is the distance from the axis of rotation.
- Rotational inertia of multiple objects add together algebraically.

Parallel Axis Theorem: If you know an object's rotational inertia about its center of mass, the rotational inertia I' about a parallel axis is given by $I' = I_{cm} + Md^2$, where d is the distance from the new axis to the center of mass.

7.3 Newton's Second Law for Rotation

An angular acceleration is caused by a net torque: $\alpha = \frac{\tau_{net}}{I}$

7.4 Angular Momentum

- Before calculating angular momentum, it is necessary to define a rotational axis.
- The angular momentum L of an object is given by:
  - $I\omega$ for an extended object
  - mvr for a point object, *For a object moving in a straight line a constant speed, r represents the "distance of closest approach."*

7.5 Conservation of angular momentum

- When no torques act external to a system, angular momentum of the system cannot change.
- Angular momentum is a vector – angular momentums in the same sense add, angular momentums in opposite senses subtract.
- Angular momentum is conserved separately from linear momentum. **Do not combine them in a single equation.**

7.6 Angular Impulse

The impulse-momentum theorem can be written for angular momentum, too. $\tau\Delta t = \Delta L$
A change in angular momentum equals the net torque multiplied by the time the torque is applied.

8 Simple Harmonic Motion

- Many objects that vibrate back-and-forth exhibit simple harmonic motion. The pendulum and the mass-ona-spring are the most common examples of simple harmonic motion.
- An object in simple harmonic motion makes a position-time graph in the shape of a sine function. The equation for position as a function of time is $x = A\cos(2\pi ft)$.
- An object in simple harmonic motion experiences a net force whose
  - magnitude increases a linear function of distance from the equilibrium position
  - direction always points toward the equilibrium position
- Definitions involving simple harmonic motion:
  - Amplitude (A): The maximum distance from the equilibrium position reached by an object in simple harmonic motion
  - Period (T): The time for an object to complete one entire vibration.
  - Frequency (f): How many entire vibrations an object makes each second.
- The period of an object on a spring is given by the equation $T_s = 2\pi\sqrt{\frac{m}{k}}$. The mass attached to the spring is m; the spring constant of the spring is k.
- The period of a pendulum is given by the equation $T_p = 2\pi\sqrt{\frac{\ell}{g}}$. The length of the pendulum is L; the gravitational field is g

8.1 Force of a spring

- A spring pulls with more force the farther the string is stretched or compressed.
- The force of a spring is given by the equation $F = kx$. Here, k is the spring constant of the spring, and x is the distance the spring is stretched or compressed from its equilibrium position.
- The spring constant is a property of a spring, and is always the same for the same spring.
- The standard units of the spring constant are N/m.

8.2 Vertical Springs

- When dealing with an object hanging vertically from a spring, it's easiest to consider the spring-earth-object system.
- The potential energy of the spring-earth-object system is $PE = \frac{1}{2}kx^2$, where x is measured from the *position where the object would hang in equilibrium.*

9 Fluids

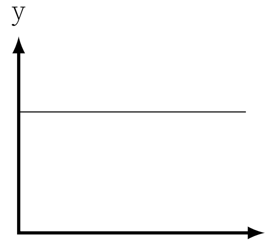
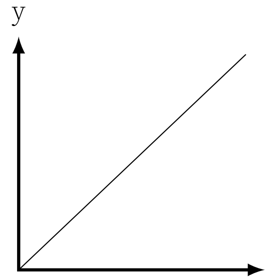
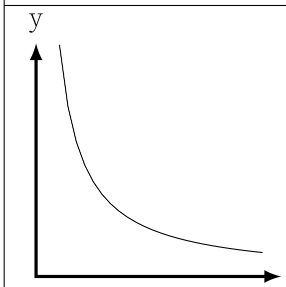
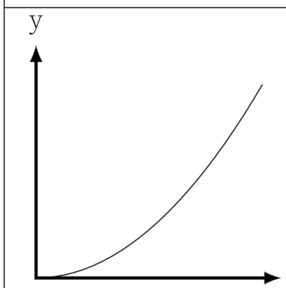
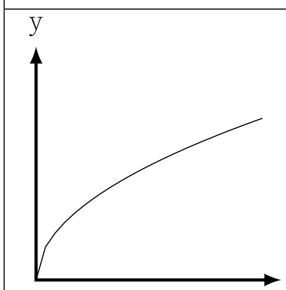
9.1 Static Fluids

- The pressure in a static column of fluid is $P = P_0 + \rho g h$; Here the $\rho g h$ term is called the "gauge pressure," meaning the pressure above atmospheric.
- Density, ρ, is defined as mass/volume. Thus, mass can be expressed as ρV.
- The buoyant force on an object is equal to the weight of the fluid displaced.
- The equation for the buoyant force is FB = rVg, where r is the density of the FLUID and V is the volume SUBMERGED.

9.2 Flowing fluids

- The continuity principle is a statement of conservation of mass: the volume flow rate (or mass flow rate) must be the same everywhere.
- The continuity principle for flow of cross sectional area A and speed v says $A_1 v_1 = A_2 v_2$.
- Bernoulli's equation is a statement of conservation of energy.
- Bernoulli's equation says $P + \rho g h + \frac{1}{2}\rho v^2$ is constant at any two locations.

10 Five Types of Graphs to Know

Graph Shape	**Written Relationship**	Modification required to linearize graph	Algebraic Relationship
	As x increases, y remains the same. There is no relationship between the variables.	None	$y = b$, or y is constant
	As x increases, y increases proportionally. y is directly proportional to x OR as x increases y increases linearly with x	None	$y = mx + b$
	As x increases, y decreases. y is inversely proportional to x	Graph y vs. $\frac{1}{x}$, or y vs. x^{-1}	$y = m(\frac{1}{x}) + b$
	y is proportional to the square of x.	Graph y vs. x^2	$y = mx^2 + b$
	The square of y is proportional to x.	Graph y^2 vs. x	$y^2 = mx + b$

****There are no exponential relationships in AP Physics 1****